

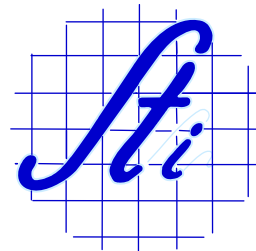
# Development of a Vehicle Model/Simulation Evaluation Tool

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# Report Documentation Page

*Form Approved*  
*OMB No. 0704-0188*

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1. REPORT DATE <b>16 APR 2008</b>	2. REPORT TYPE <b>N/A</b>	3. DATES COVERED <b>-</b>	
4. TITLE AND SUBTITLE <b>Development of a Vehicle Model/Simulation Evaluation Tool</b>		5a. CONTRACT NUMBER	
		5b. GRANT NUMBER	
		5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) <b>J. Gavin Howe; Jeffrey P. Chrstos; Richard Romano; James O’Kins</b>		5d. PROJECT NUMBER	
		5e. TASK NUMBER	
		5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>US Army RDECOM-TARDEC 6501 E 11 Mile Rd Warren, MI 48397-5000</b>		8. PERFORMING ORGANIZATION REPORT NUMBER <b>18799</b>	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S) <b>TACOM/TARDEC</b>	
		11. SPONSOR/MONITOR’S REPORT NUMBER(S) <b>18799</b>	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release, distribution unlimited</b>			
13. SUPPLEMENTARY NOTES <b>Presented at SAE 2008 World Congress, April 14-17, 2008, Detroit, Michigan, The original document contains color images.</b>			
14. ABSTRACT			
15. SUBJECT TERMS			
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>SAR</b>
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>	
19a. NAME OF RESPONSIBLE PERSON			

# Overview

- To evaluate vehicle simulation models, there is a need to compare simulation results to test data and/or results from higher fidelity simulations.
- Several types of tests and/or maneuvers may need to be compared.
- Military procurement requirements.
- A process/tool for evaluation of vehicle simulation models has been developed.

# Evaluation Types

A thorough evaluation will include:

- Laboratory type tests - weight distribution, kinematics and compliance, steering ratio, and other static measures.
- Dynamic maneuvers - handling, drive train, braking, ride, and obstacle types.

# Historical Background

- In 1990, Heydinger, et. al. presented a methodology for validating vehicle dynamics simulation that compared vehicle simulation results to physical testing
  - "A... ..mathematical model... ..will be considered to be valid if, within some specified operating range of a system, a simulation's predictions of a system's responses of interest to specified input(s) agree with the actual physical system's responses to the same input(s) to within some specified level of accuracy"

# Historical Background

- In 1994, Bernard and Clover suggested that three separate questions need to be addressed in the validation process:
  - Is the model appropriate for the vehicle and maneuver of interest?
  - Is the simulation based on equations that faithfully replicate the model?
  - Are the input parameters reasonable?

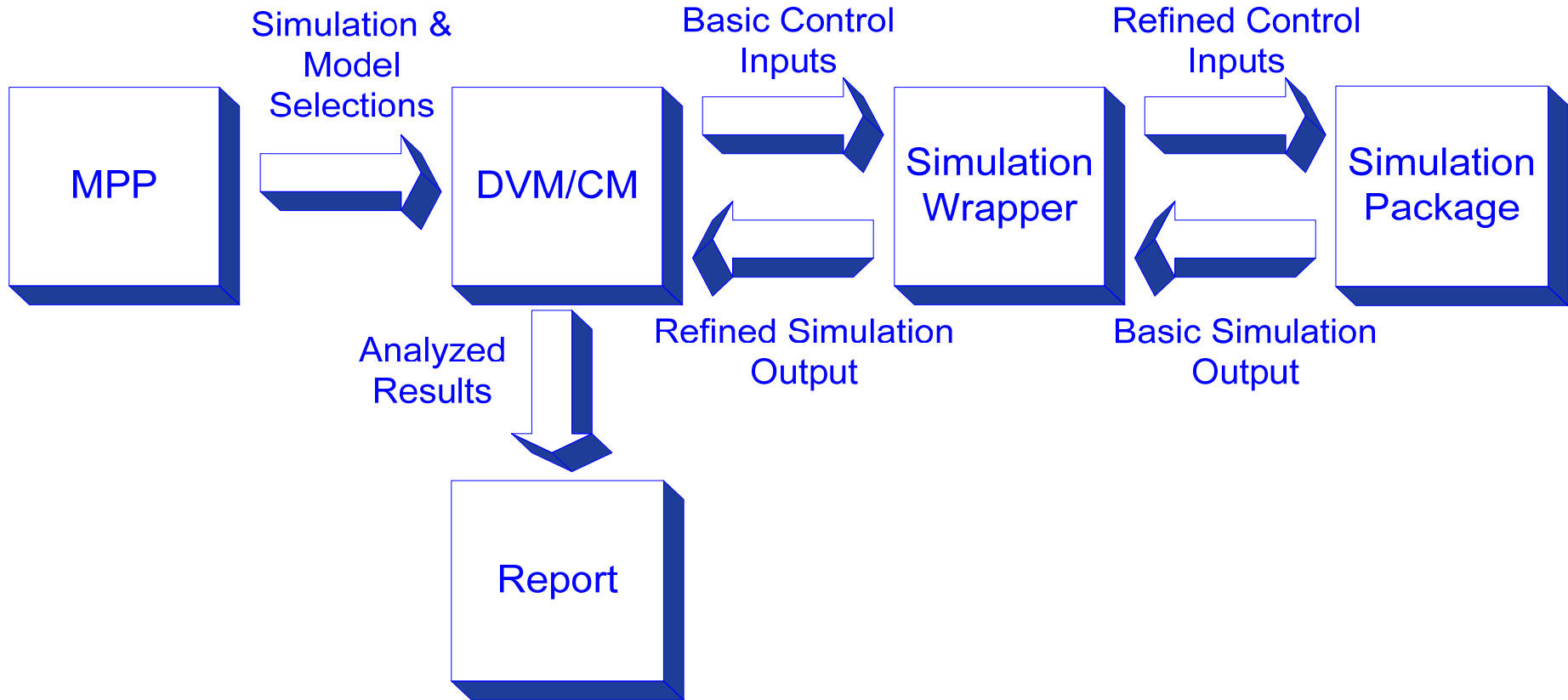
# Model Post Processor (MPP)

- This tool allows a vehicle dynamicist to evaluate simulations and/or models by:
  - selecting vehicle models from a variety of simulation programs;
  - evaluating/comparing/contrasting models using static vehicle metrics;
  - and evaluating models using dynamic vehicle maneuvers.

# MPP Subcomponents

- Dynamic Vehicle Metrics (DVM) - consists of a wide range of dynamic vehicle maneuvers
  - Ride and handling, Braking, Acceleration, etc.
- Consistency Metrics (CM) - consists of a set of quasi-static vehicle tests
  - K and C, steering ratio, etc.

# MPP Flow Diagram



# Implementation Details

- Directory Structures
  - Models, Simulation Results
- File Naming Conventions
  - Maneuver/test results for each model
- Output Data Structures
  - How are the results saved for consistency
- Command Files
  - Steering, braking, throttle, speed, gear, etc.
- Simulation Wrappers
- Reporting Options
  - General output types; Maneuver/test specific output
- Data Shared Between the CM and DVM

Pull Down Menus →

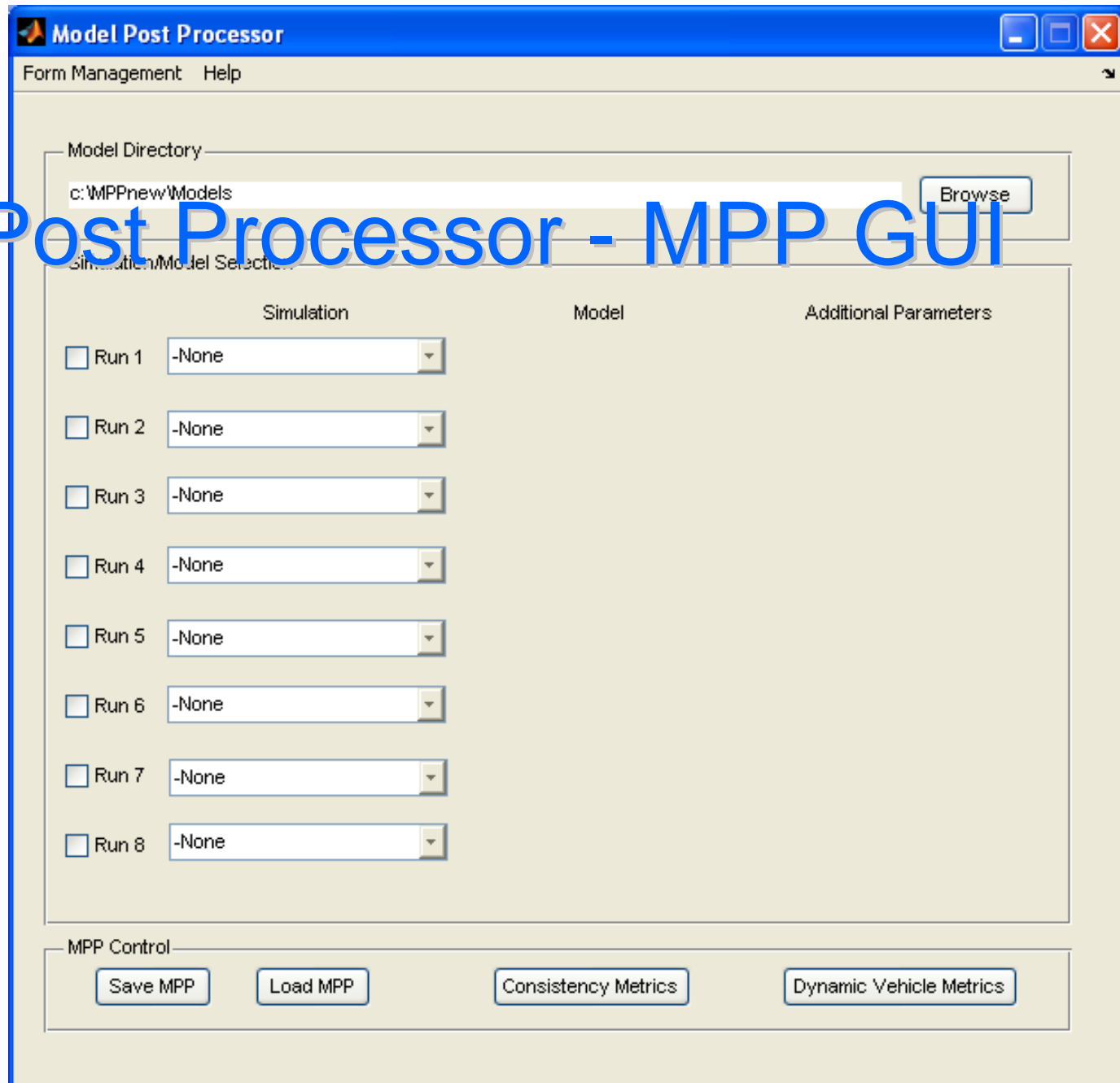
Model Directory

Selection ↑

# Model Post Processor - MPP GUI

Simulation/Model Selection →

MPP Control →



# MPP Simulation/Model Selection

Model Directory  
c:\MPPnew\Models Browse

Simulation/Model Selection

	Simulation	Model	Additional Parameters
<input checked="" type="checkbox"/> Run 1	VDANL	Cherokee	-None
<input type="checkbox"/> Run 2	-None		-None
<input type="checkbox"/> Run 3	-None		Heavy.vpf
<input type="checkbox"/> Run 4	-None		Light.vpf
<input type="checkbox"/> Run 5	-None		
<input type="checkbox"/> Run 6	-None		
<input type="checkbox"/> Run 7	-None		
<input type="checkbox"/> Run 8	-None		

MPP Control

Save MPP Load MPP Consistency Metrics Dynamic Vehicle Metrics

# Consistency Metrics (CM)

- A set of quasi-static tests used to evaluate a model
- Kinematics and Compliance (K & C) type tests
- Static test to determine weight distribution
- Steering Ratio test

# Kinematics and Compliance

## ➤ Kinematic Tests

- vertical motions applied to the tire ground contacts to exercise the suspension
- horizontal tire forces and moments are controlled to be zero

## ➤ Compliance Tests

- lateral and longitudinal forces and aligning moments are applied to tire contact patches
- virtual ground plane is held fixed

# CM List of Tests

- Static Test – Weight Distribution
- Kinematic Heave
- Kinematic Roll
- Lateral Compliance
- Longitudinal In-Phase Compliance
- Out-of-Phase Compliance
- Aligning Moment Compliance
- Steering Ratio Test

# CM Virtual Restraint System

- Consists of three linear spring/dampers and three rotary spring/dampers acting at the vehicle sprung center of gravity
- Linear spring stiffness set to allow 0.0254 mm (0.001 in) deflection under a load equal to the total vehicle weight
- Rotary springs set to allow 0.0254 mm (0.001 in) deflection when a load equal to the total vehicle weight is applied to a single wheel

# CM Virtual Restraint System – Springs

$$K_x = K_y = K_z = \frac{W \cdot MaxLoad}{\Delta_{max}} \left( \frac{N}{m} \right)$$

$$Km_x = \frac{W \cdot MaxLoad \cdot 0.5 \cdot TW}{\tan^{-1} \left( \frac{\Delta_{max}}{0.5 \cdot TW} \right)} \left( \frac{N \cdot m}{rad} \right)$$

$$Km_y = Km_z = \frac{W \cdot MaxLoad \cdot A}{\tan^{-1} \left( \frac{\Delta_{max}}{A} \right)} \left( \frac{N \cdot m}{rad} \right)$$

Variable	Description	Units
$K_x$	Longitudinal restraint stiffness	N/m
$K_y$	Lateral restraint stiffness	N/m
$K_z$	Vertical restraint stiffness	N/m
$W$	Total vehicle weight	N
$MaxLoad$	Multiplier of total weight to set maximum applied load	-
$\Delta_{max}$	Allowable deflection at max loading	m
$Km_x$	Rotary stiffness about longitudinal axis	Nm/rad
$Km_y$	Rotary stiffness about lateral axis	Nm/rad
$Km_z$	Rotary stiffness about vertical axis	Nm/rad
$TW$	Front axle track width	m
$A$	Distance from sprung c.g. to front axle	m

Test List ↓

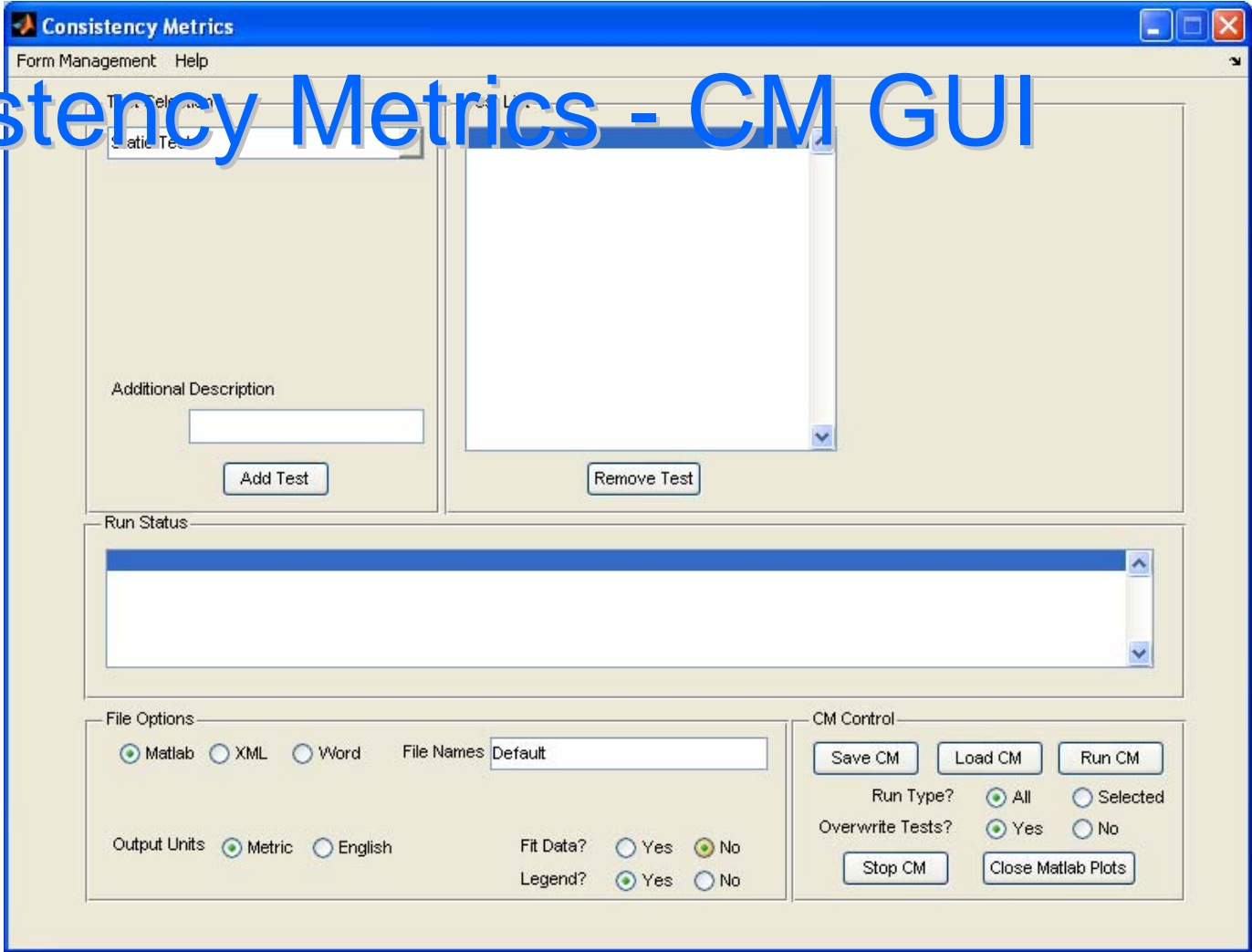
Pull Down Menus →

# Consistency Metrics - CM GUI

Test Selection →

Run Status →

File Options →



CM Control ↑

Test Selection

Kinematic Heave

Max Tire Load (% Veh Wgt)

100  
0.01

Ramp Rate (m/s)

Additional Description

1 cm/s

Add Test

Test List

Kinematic Heave - 1 cm/s

Remove Test

Max Tire Load (% Veh Wgt)

100

Ramp Rate (m/s)

0.01

Additional Description

1 cm/s

CM Test Selection

Run Status

File Options

Matlab  XML  Word

File Names Default

Output Units  Metric  English

Fit Data?  Yes  No

Legend?  Yes  No

CM Control

**Save CM** Load CM Run CM

Run Type?  All  Selected

Overwrite Tests?  Yes  No

Stop CM Close Matlab Plots

Test Selection

Steering Ratio

Max Steer (rad)

Ramp Rate (rad/s)

Additional Description

0.3 rad/s

Add Test

Test List

Static Test - Basic

Kinematic Heave - 1 cm/s

Steering Ratio - 0.3 rad/s

Max Steer (rad)

6

Ramp Rate (rad/s)

0.3

Additional Description

0.3 rad/s

Remove Test

CM Test List Area

Run Status

Run Status area containing a large empty text box with a blue header bar and scrollbars.

File Options

Matlab  XML  Word

File Names Default

Output Units  Metric  English

Fit Data?  Yes  No

Legend?  Yes  No

CM Control

Save CM

Load CM

Run CM

Run Type?  All  Selected

Overwrite Tests?  Yes  No

Stop CM

Close Matlab Plots

# Consistency Metrics

Form Management Help

## Test Selection

Steering Ratio

Max Steer (rad)

Ramp Rate (rad/s)

Additional Description

Add Test

## Test List

- Static Test - Basic
- Kinematic Heave - 1 cm/s
- Steering Ratio - 0.3 rad/s**

Remove Test

Max Steer (rad)

Ramp Rate (rad/s)

Additional Description

# CM Run Status Panel

## Run Status

Running Cherokee - STT  
Will create c:\MPPnew\CMSimulationResults\WDANL\Cherokee\Default\DefaultSTT\_1.mat  
Running Cherokee - KCH  
Will create c:\MPPnew\CMSimulationResults\WDANL\Cherokee\Default\DefaultKCH\_2.mat  
Running Cherokee - SRT  
Will create c:\MPPnew\CMSimulationResults\WDANL\Cherokee\Default\DefaultSRT\_3.mat

## File Options

Matlab  XML  Word

File Names

Output Units  Metric  English

Fit Data?  Yes  No

Legend?  Yes  No

## CM Control

Save CM

Load CM

Run CM

Run Type?  All  Selected

Overwrite Tests?  Yes  No

Stop CM

Close Matlab Plots

# Dynamic Vehicle Metrics (DVM)

- A set of dynamic vehicle tests that are used to assess powertrain, braking, handling, and ride performance
- Steering, brake, and throttle/speed vehicle inputs
- Terrain profile for ride type tests
- Hitch force for Drawbar test

# DVM Maneuvers

- Slowly Increasing Steer, J-Turn, Swept Sine, Fishhook
- Straight Line Acceleration/Deceleration
- Straight Line and Slowly Increasing Brake
- Trapezoidal Bump, Pothole, Half Round, Washboard, RMS Course
- Drawbar Pull

Maneuver List ↓

Pull Down Menus →

# Dynamic Vehicle Metrics – DVM

## GUI

Maneuver Selection →

Run Status →

File Options →

Dynamic Vehicle Metrics

Form Management Help RMS Course Values

Maneuver Selection

Slowly Increasing Steer

Maneuver Inputs

Vehicle Speed (m/s)

Max Steer Angle (rad)

Steer Rate (rad/s)

Gear Number

Additional Description

Add Maneuver

Maneuver List

Remove Maneuver

Maneuver Inputs

Run Status

File Options

Matlab  XML  Word File Names Default

Output Units  Metric  English

Legend?  Yes  No

Display Only Summary Plots?  Yes  No

DVM Control

Save DVM Load DVM Run DVM

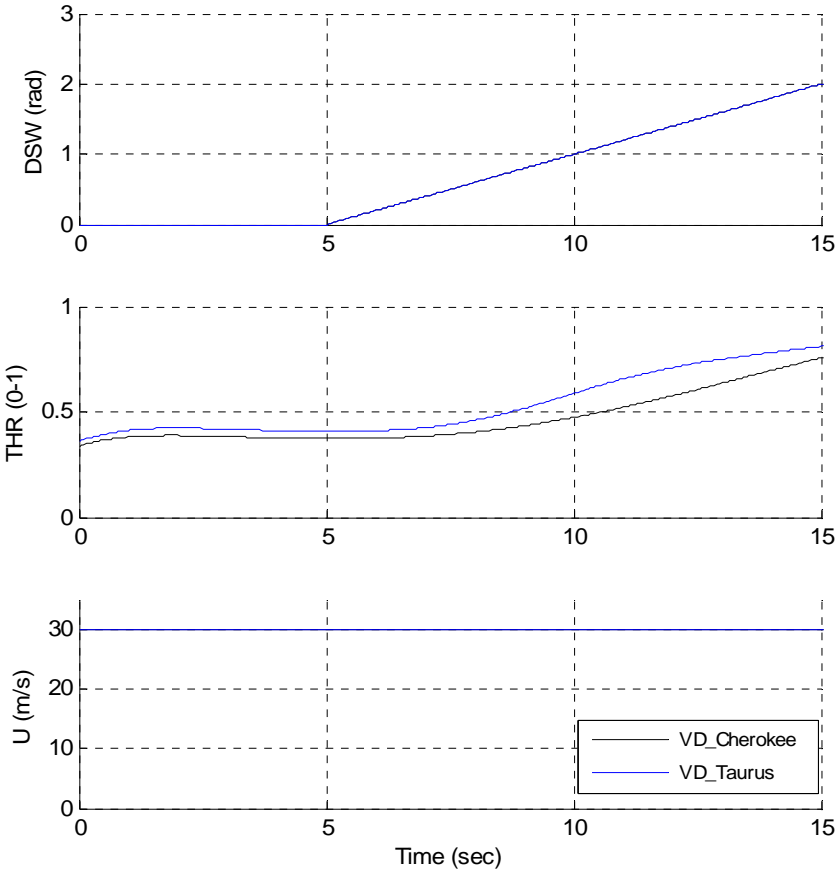
Run Type?  All  Selected

Overwrite Maneuvers?  Yes  No

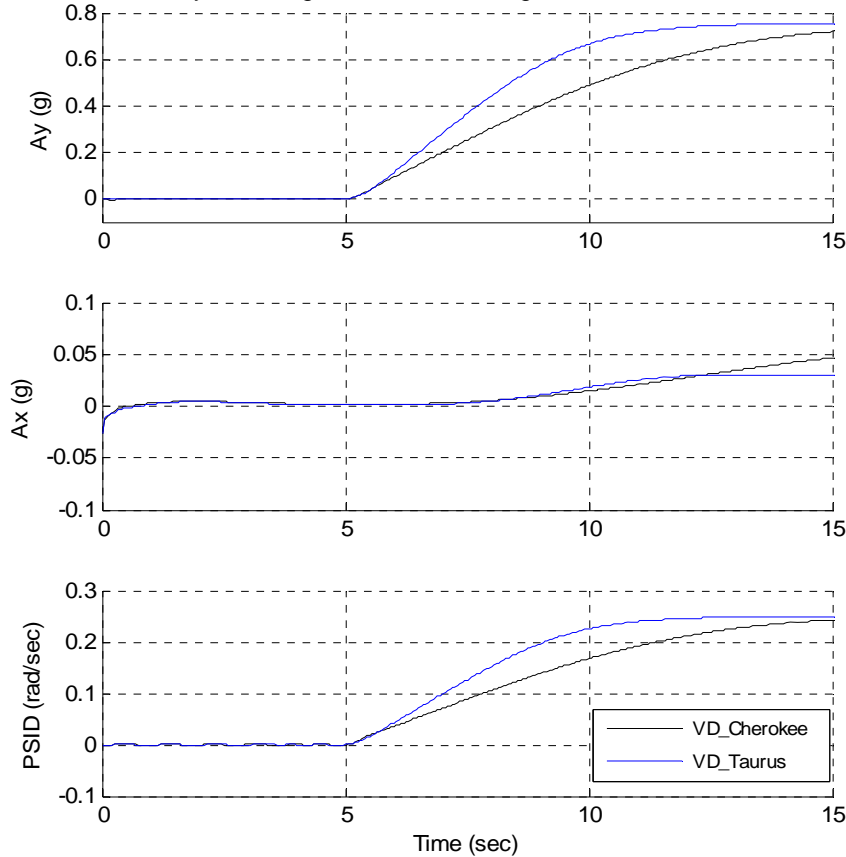
Stop DVM Close Matlab Plots

# Example Output

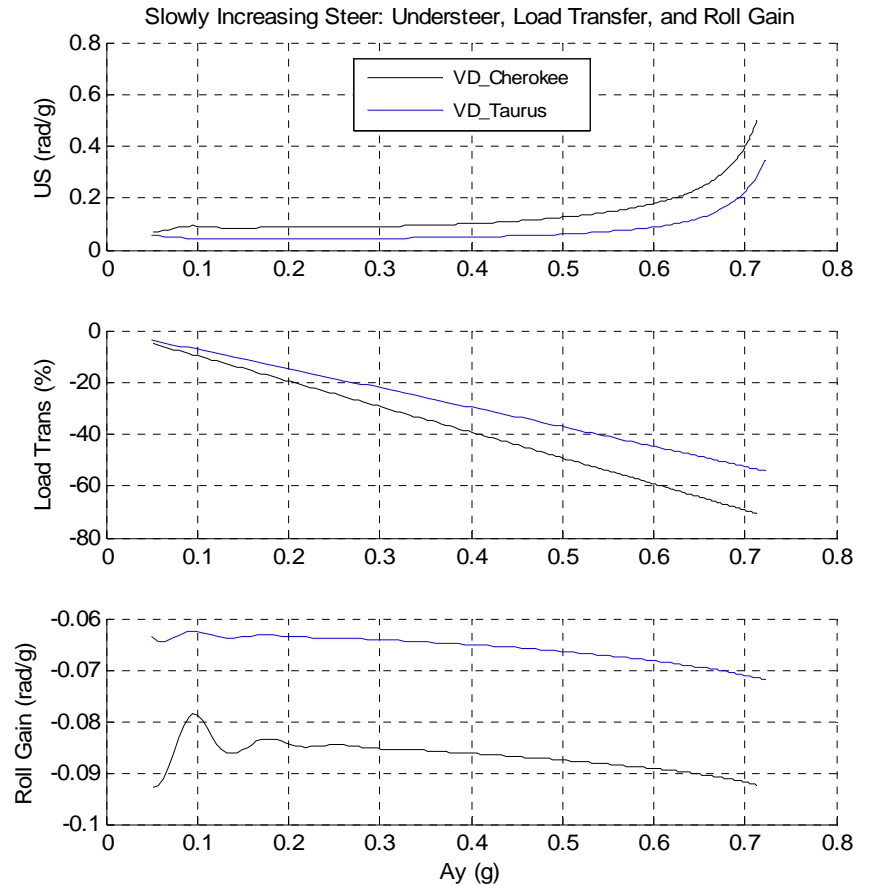
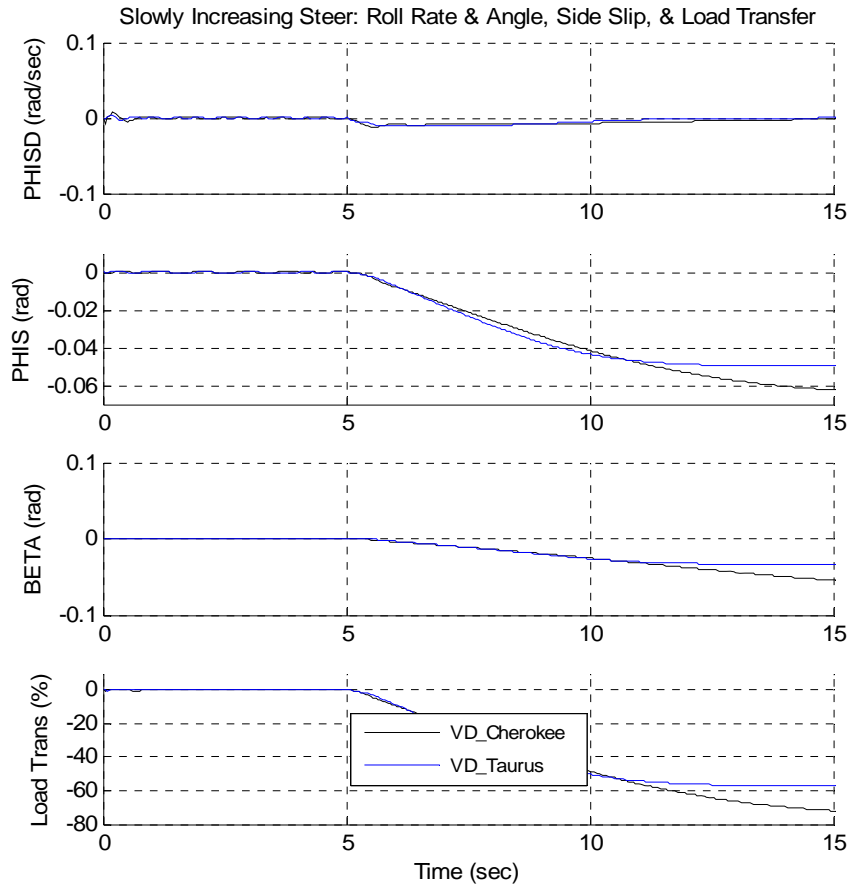
Slowly Increasing Steer: Steering, Throttle, & Speed



Slowly Increasing Steer: Lateral & Longitudinal Accel & Yaw Rate



# Example Output



# Example Output

Table 1 - Understeer Gradient at Various Lateral Accelerations

	VD_Cherokee	VD_Taurus
Lateral Acceleration	Understeer Gradient	Understeer Gradient
(g)	(rad/g)	(rad/g)
0.1	0.0928	0.0451
0.2	0.0870	0.0437
0.3	0.0906	0.0452
0.4	0.1013	0.0500
0.5	0.1252	0.0605
0.6	0.1790	0.0882
0.7	0.4008	0.2243

# Example Output

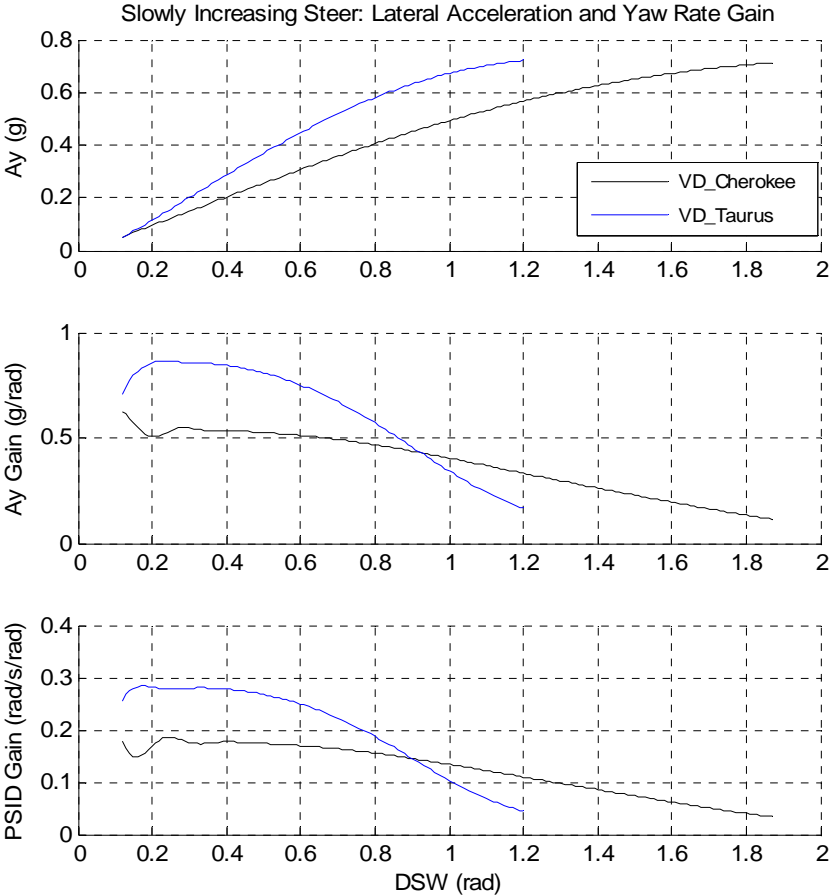


Table 5 - Lateral Acceleration Gain at Various Steering Wheel Angles

	VD_Cherokee	VD_Taurus
Steering Wheel Angle	Lateral Acceleration Gain	Lateral Acceleration Gain
(rad)	(g/rad)	(g/rad)
0.5	0.5250	0.8083
1.0	0.4036	0.3428
1.5	0.2282	-

# Conclusions

- The development of a vehicle model/simulation evaluation tool was presented (MPP).
- Simulation/models can be evaluated using static vehicle metrics (CM).
- Simulation/models can be evaluated using dynamic vehicle maneuvers (DVM).
- Allows comparison of:
  - vehicle models for the same simulation;
  - vehicle models for different simulations;
  - vehicle models to physical test data.
- Results can be output to multiple formats.